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A study on Strength Characteristics of High Performance Densified Small Particles Based Concrete

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Abstract*— Concrete is used most widely as a construction material. The primary difference between conventional concrete and high performance concrete is the use of mineral and chemical admixtures. High Performance Densified Small Particles based Concrete is a concrete which is obtained by using high quantities of superplasticizers and high volumes of microsilica. It ensures proper filling and good structural performance. In general, when fibres are added to concrete, tensile strain of the fibre improves significantly. This in turn improves cracking behavior, ductility and energy absorption capacity of composites in addition to durability. This work outlines investigation on the Strength properties of Densified Small Particles based Concrete of grade M70 with brass coated straight steel fibres. The Compressive, Flexural and Split Tensile strength tests for different percentage of steel fibres i.e. 0, 3, 6, 9 and 12% by weight of cementitious material were performed at 7, 14 and 28 days. The investigations show that, the Compressive, Flexural and Split Tensile Strength at 9% steel fibres are higher. With increase in steel fibre percentage from 9% to 12% there is no appreciable increase in Compressive strength, Flexural strength as well as in Split tensile strength. From 9% to 12% concrete is not workable and hence 9% is considered as optimized value.

***Keywords*— M70 grade, High Performance Densified Small Particles Based Concrete, Microsilica, Brass Coated Straight Steel Fibres, Superplasticizer**

I. Introduction

Concrete is primary part of development in all countries especially in a developing country like India with annual consumption exceeding 100 million cubic meters. Very low tensile strength, limited ductility and lesser resistance to cracking is possessed by Ordinary cement concrete. The concrete fails to handle tensile loading because it shows brittle behavior hence leads to internal micro cracks which are mainly responsible for brittle failure of concrete. It is well known that the main parameter for which the conventional concrete designed is compressive strength which does not meet many functional requirements like impermeability, resistance to frost, thermal cracking adequately. Considerable attempts have been made in recent past for improving the properties of concrete with respect to strength and durability, especially in aggressive environments. For a strong and durable structure, High performance concrete appears to be a better choice. Various environmental as well as health problems are caused due to dumping and disposal of large amount of by-product or wastes like fly-ash, copper slag, silica fume etc. which are generated by industries. Both the durability and mechanical properties of the concrete can be improved by proper introduction of silica fume in concrete.

The CC has four major constituents which are cement, aggregates, water and admixtures. Whereas High Performance Concrete has five major constituents that are mineral admixtures such as silica fumes, rice husk ash, fly ash, lime powder and ground granulated blast furnace slag have been used in the development of HPC. Therefore, the primary difference between HPC and Conventional concrete is the use of mineral and chemical admixtures. It has been practically observed that by addition of mineral admixtures in the concrete, there is help in attaining the properties i.e. compressive strength or durability performance, but also at the same time, chemical admixtures like High Range Water Reducers (HRWR) and Viscosity Modifying Agents (VMA) are required so as to ensure that the mixing, transportation, placing and finishing of concrete done easily. The key elements of high performance concrete are Low water-to-cement ratio, Large quantity of silica fume and other fine mineral powders, Small aggregates and fine sand, and High dosage of super plasticizers.

Fiber-reinforced concrete (FRC) is defined as the concrete which contain fibrous material and increases its structural integrity. It includes short discrete fibers which are distributed uniformly and oriented randomly. Fibers include different types of fibres such as glass fibers, steel fibers, natural fibers and synthetic fibers – each of which lends different properties to the concrete. In addition, fiber-reinforced concrete character alters with varying concretes, fiber materials, distribution, geometries, densities and orientation. High Performance Fiber Reinforced Concrete (HPFRC) is an FRC sub-category which claims 500 times more resistance to cracking and 40 percent lighter because of reduced weight than traditional concrete and claims it can sustain strain-hardening up to several percent strain, resulting in a material ductility of at least two orders of magnitude greater as compared to normal concrete or standard fiber-reinforced concrete.

By using higher quantities of superplasticizers and higher volumes of microsilica, DSP materials, including fiber-reinforced DSP and CRC (Compact Reinforced Composites) can be obtained. The Densified with small particles concept was given in 1980's by Bache, when the idea of using sub-micron particles (microsilica) addition in cementitious materials was conceived. Densified with Small Particle cement pastes include a mixture of the Portland cement and microsilica, densified with a superplasticizer Normally, the ratio of water/binder varies from 0.15 - 0.20 and the microsilica/ binder ratio may varies from 0.15 - 0.25.

II. MATERIALS

In this study, the constituent materials which are required for densified small particle based concrete are cement, coarse aggregates, fine aggregates, silica fume, superplasticizer, brass coated steel fibres, and water. The materials were tested according to Indian Standards procedure to check their suitability. The collections of raw materials were made from the locally available sources from the market.

A. **Cement**

Ordinary Portland Cement of Grade 43 was used from "ULTRA TECH" in the experimental work which is confirming to IS:8112:2013. The value of normal consistency, specific gravity, soundness, fineness, initial and final setting time are 29.5, 3.05, 2.3 mm, 90 minutes and 185 minutes.

B. **Fine Aggregates**

Natural river sand as per IS:383 confirming to Zone II was used as fine aggregate. The values of fineness modulus, specific gravity, and water absorption are 2.69, 2.64 and 2.28 respectively.

C. **Coarse Aggregates**

In the experimental work, the crushed stone aggregate having size 10mm were used. The sieve analysis according to IS:383 was used to determine the grading of the coarse aggregate. The values of specific gravity, crushing value, impact value and water absorption are 2.70, 23.33, 24.94 and 2.32 respectively.

D. **Silica Fume**

In this experimental work, micro silica fume with specific surface 18 m^2/g and specific gravity of 2.3 has been used which is confirming as per IS:15388-2003 and supplied by "ELKEM" of 920D grade. It consist a dry powder which helps in improving the performance of mortar and concrete. It as a highly reactive pozzolana chemically and physically it acts to optimize particle packing of the concrete. Fig. 1 show the silica fume:

Fig. 1 Microsilica Fume

E. **Steel Fibres**

Fig. 2 show the Brass Coated Steel Fibres obtained from FIBERZONE Ahmedabad have been used which have greater tensile strength and can be integrated and dispersed with concrete.

Fig. 2 Brass Coated Steel Fibres

The values of length, diameter, aspect ratio, tensile strength and density of Steel Fibres are 8mm, 0.24 mm, 33.33 and 7.85 g/cm^3 respectively.

F. **Super Plasticizer**

"Auramix 400" which is manufactured by "Fosroc Ltd" was used as superplasticizer in the study and is a unique combination of the latest generation superplasticizer, based on a polycarboxylic ether polymer with long lateral chains with relative density of 1.02 at 25°C. This significantly enhances cement dispersion. At the beginning of the mixing operation an electrostatic dispersion occurs but to separate and disperse the cement particles. This mechanism reduces the water demand in self compacting concrete of flowable concrete.

H. **Water**

Potable water which is fit for drinking purposes and free from any deleterious material has been used as prescribed by IS:456-2000, for mixing the concrete mix also in curing of samples for the experimental work.

III. EXPERIMENTAL PROGRAMME

A. **Concrete Mix Design**

A number of trial mixes were carried out so that High Performance Concrete can be achieved by using Microsilica Fume and High Range Water Reducing agent (HRWR). To achieve slump of 100±5mm, water–Cement ratio was adjusted. A number of trial mixes as proposed by various researchers were tried to achieve HPDSPC of M70 grade. Finally to achieve compressive strength corresponding to M70, a High Performance Concrete mix was designed by using the different constituents according to ACI Committee 211.4-08 shown in Table 1:

Concrete mix proportion corresponding to 1 : 0.112 : 2.22 : 1.473 : 0.28 : 1.4 has been used which represents cement, silica fume, 10 mm coarse aggregate, fine aggregate, w/c ratio and HRWR in casting of control specimens and also with fibre contents which are varying from 0% to 9 %.

Table 1 Concrete Mix Proportion

Cement (kg/m^3)	Silica Fume (kg/m^3)	Coarse Aggregate (kg/m^3)	Fine Aggregate (kg/m^3)	Water Cement Ratio	HRWR (% by weight of cement)	Average Compressive Strength (N/mm^2)	
						7 Days	28 Days
475	53	1055	700	0.28	1.4	62.00	71.40

B. **Methodology**

- The raw materials were collected which were required for casting the concrete mix specimens. Then the physical properties of raw materials were tested in the laboratory.
- By using weighing balance, the quantities of materials have been weighted.
- Before preparing the mix the test moulds were kept ready and all contact surfaces of the moulds were cleaned and oiled.
- Brass coated straight steel fibres have been added by weight of cementitious material in the varying percentage of 0%, 3%, 6%, 9% and 12%.
- The HPDSP concrete mix cubes of size 150mm x 150mm x 150mm, cylinders of size 100mm diameter and 200mm height, and beams of size 100mm x 100mm x 500mm with different fibre percentage were casted and cured for 7 days, 14 days and 28 days to perform compressive strength, flexural strength and split tensile strength test.
- A set of three samples of cubes, three samples of beams and three samples of cylinders have been casted for each test and the average value of the three samples has been taken as final value of strength.
- The test for compressive strength, flexural strength and split tensile strength have been performed for each set of three cubes after 7days, 14 days and 28 days of water curing.

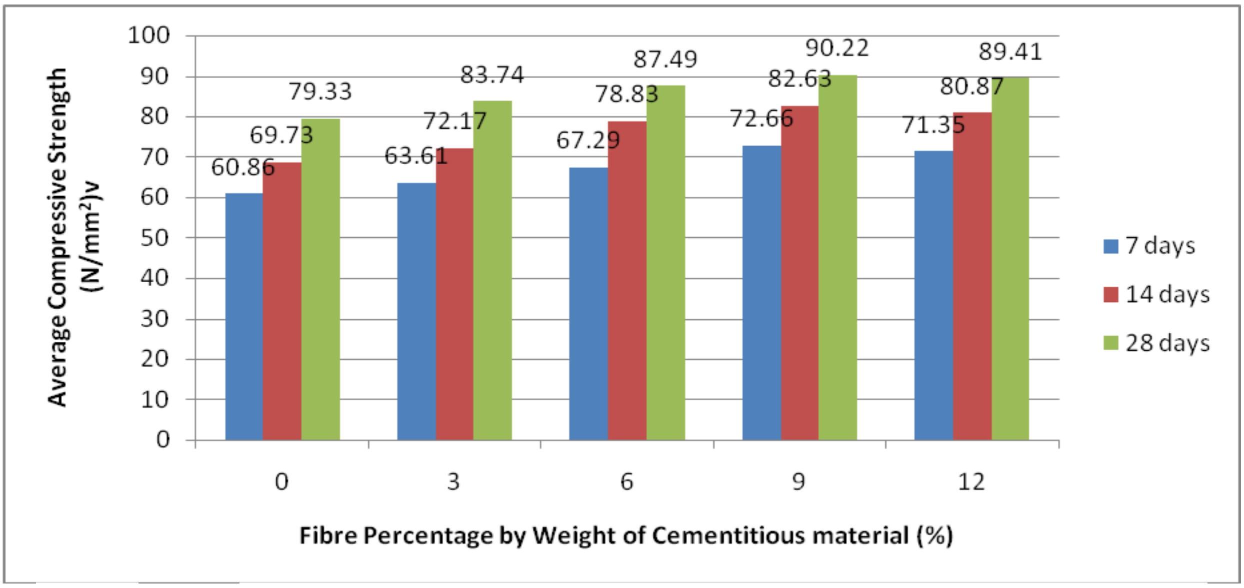
IV. RESULTS AND DISCUSSIONS

A. **Compressive Strength Test**

Table 2 gives the test results of the average compressive strength of HPDSPC cube samples with different percentage of the fibres from 0, 3, 6, 9, and 12 percent by weight of cementitious material for 7 days, 14 days and 28 days. The compressive strength of HPDSP concrete without steel fibres has been obtained as **79.33 N/mm^2** and maximum compressive strength for HPDSP concrete cubes with **9%** steel fibres is **90.22 N/mm^2**. On further addition of fibres upto 12%, there is decrease in compressive strength after 9% fibres due to less or negligible bonding of concrete materials.
This illustrates that compressive strength of HPDSP concrete specimen did not increase significantly after 12% fibres. The cubes without steel fibres breaks completely at failure load of **1785 KN** and the cube with 9% fibres volume breaks at failure load of **2030 KN** which doesn't break completely at failure because the fibres help in microstructure bonding of concrete material and helps in holding the fibrous concrete material and therefore reducing the brittleness of concrete.

Table 2 Compressive Strength of Concrete Mix by Addition of Different %age of Steel Fibres

Fibre Percentage by Weight (%)	Average Compressive Strength (N/mm^2)		
	7 days	**14 days**	**28 days**
0	60.86	69.73	79.33
3	63.61	72.17	83.74
6	67.29	78.83	87.49
9	**72.66**	**82.63**	**90.22**
12	71.35	80.87	89.41



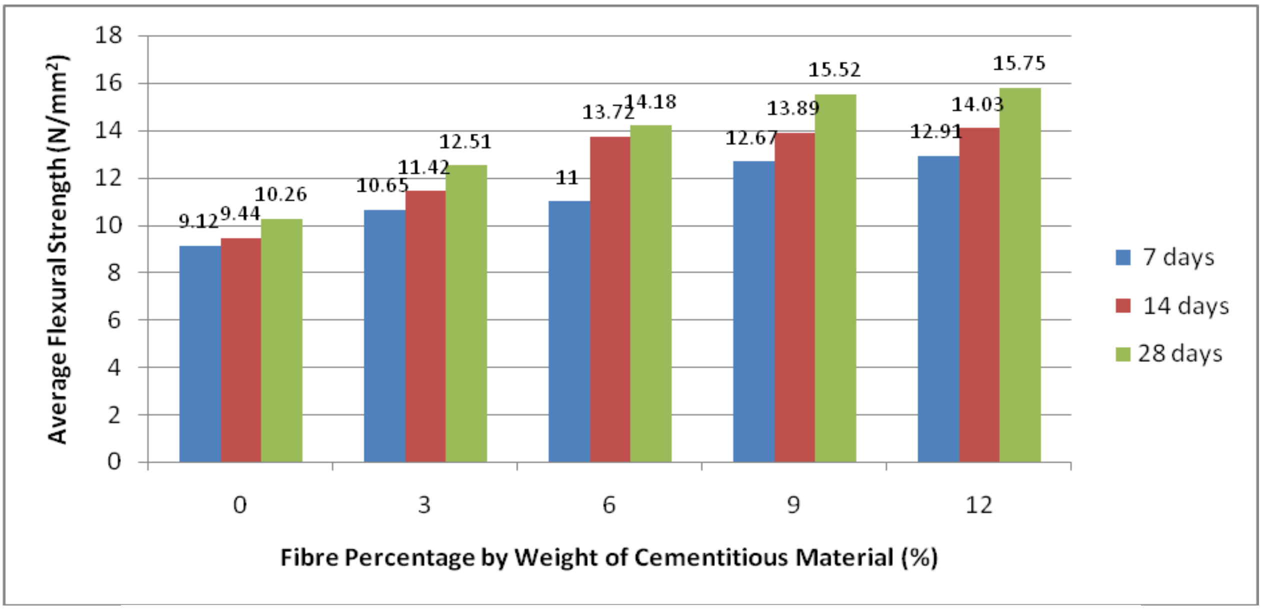
Graph 1 Average Compressive Strength of Concrete Mix by Addition of Different %age of Steel Fibres

B. **Flexural Strength Test**

Table 3 show the flexural test results of beam samples with different fibre percentage for the 7 days, 14 days and 28 days. It has been seen that the flexural strength of beams for 28 days with 9% fibres is maximum as compared to control specimen without steel fibres (0%). It was observed that the beam specimen without fibres failed at **10.26 N/mm^2** and beam specimen with 9% steel fibres failed at **15.52 N/mm^2**. At 0% fibres, beam sample show breaks into pieces and with 9% fibres, beam sample does not show break at failure load due to micro structure bonding by fibres. So, **9%** fibre is an optimum value and more effective in enhancing flexural strength in HPDSPC.

Table 3 Flexural Strength of Concrete Mix by Addition of Different %age of Steel Fibres

Fibre Percentage by Weight (%)	Average Flexural Strength (N/mm^2)		
	7 days	**14 days**	**28 days**
0	9.12	9.44	10.26
3	10.65	11.42	12.51
6	11.00	13.72	14.18
9	12.67	13.89	15.52
12	12.91	14.03	15.75



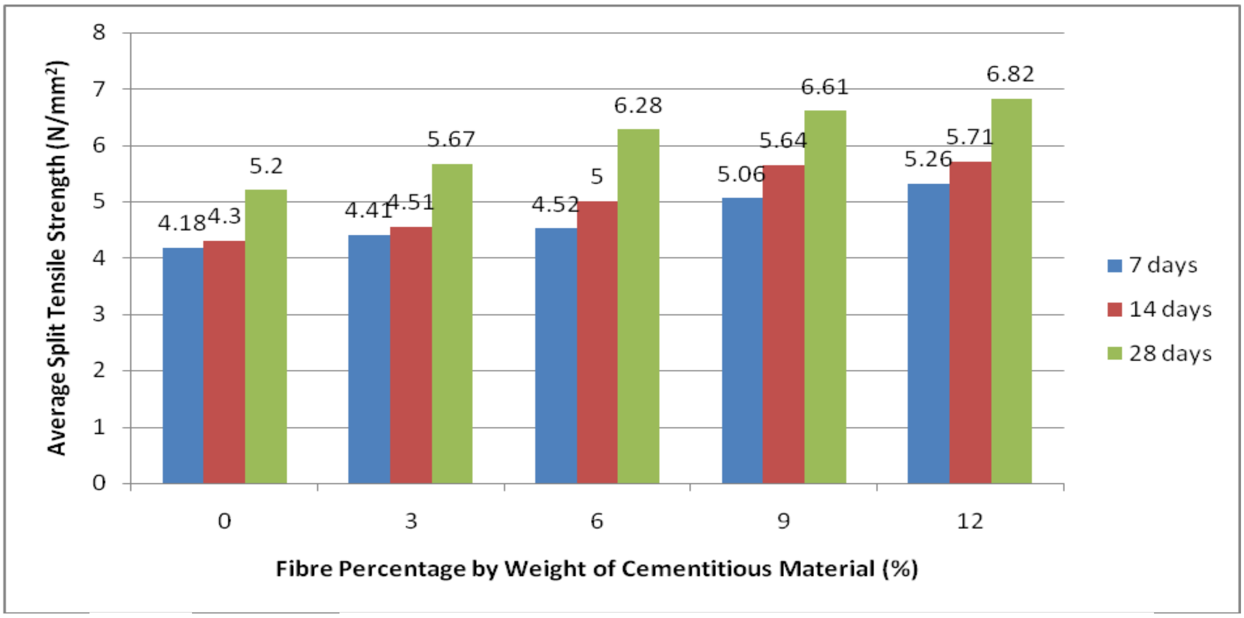
Graph 2 Flexural Strength of Concrete Mix by Addition of Different %age of Steel Fibres

C. **Split Tensile Strength Test**

Table 4 show the split tensile strength test results of cylinder samples with different fibre percentage for the 7 days, 14 days and 28 days. It has been seen that the split tensile strength of cylinders for 28 days with 9% fibres is maximum in comparison to control samples without steel fibres. It was observed that the cylinder specimen without fibres failed at 5.20 N/mm^2 and cylinder specimen with 9% steel fibres failed at 6.61 N/mm^2 after 28 days of curing. The cylinder with 0% fibres show break into pieces whereas the cylinder with 9% fibres does not show break into pieces at failure load as the fibres helps in microstructure bonding of concrete material and prevent it from breaking into pieces even at failure load. The fibres help in taking the tensile stresses and there is an appreciable increase in the split tensile strength. It may therefore be inferred that fibres are quite effective in tension and indirect tensile strength been increased significantly at **9%** fibre contents.

Table 4 Split Tensile Strength of Concrete Mix by Addition of Different %age of Steel Fibres

Fibre Percentage by Weight (%)	Average Split Tensile Strength (N/mm^2)		
	7 days	14 days	28 days
0	4.18	4.30	5.20
3	4.41	4.51	5.67
6	4.52	5.00	6.28
9	5.06	5.64	6.61
12	5.26	5.71	6.82



Graph 3 Split Tensile Strength of Concrete Mix by Addition of Different %age of Steel Fibres

V. CONCLUSION

- The study illustrate that it is possible to design HPDSPC by using silica fume and steel fibres.
- The addition of silica fume in HPDSPC improves microstructure of concrete that was helpful in enhancing the properties of concrete developed upto certain percentage.
- It is observed that compressive strength, split tensile strength and flexural strength are more for 9% fibers as compared to that produced from adding 0%, 3%, 6% and 12% fibers.
- Fibers percentages are taken with respect to cementitious material.
- All the strength properties are observed with fiber of diameter 0.24mm and length 8mm with aspect ratio of 33.33.
- The compressive strength of HPDSP concrete without steel fibres has been obtained as **79.33 N/mm^2** and maximum compressive strength for HPDSP concrete cubes with **9%** steel fibres is **90.22 N/mm^2**. On further addition of fibres upto 12%, there is decrease in compressive strength after 9% fibres due to less or negligible bonding of concrete materials.
- It was observed that the beam specimen without fibres failed at **10.26 N/mm^2** and beam specimen with 9% steel fibres failed at **15.52 N/mm^2**.
- It was observed that the cylinder specimen without fibres failed at 5.20 N/mm^2 and cylinder specimen with 9% steel fibres failed at 6.61 N/mm^2 after 28 days of curing.
- With Increase in fiber percentage from 9% to 12% there is no appreciable increase in compressive strength, split tensile as well in flexural strength. From 9% to 12% concrete is not workable and hence 9% is considered as optimized value.

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